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Viewpoint

Science, policy and the management of sewage materials. The New York City experience

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Abstract

Development of national policy on sewage sludge management is a classic example of incremental policy formulation [Fiorino, D.J. 1995. Making Environmental Policy. University of California Press. Berkeley, CA. p. 269]. Consequently, policy has developed piecemeal, and results are, in some ways, different than intended. Land application of sewage sludge has not been a panacea. Many of the same types of policy are now being raised about it. We demonstrate this by examining the management of sewage materials by New York City from near the turn of the 20th century, when ocean dumping was viewed as a means to alleviate some of the gross pollution in New York Harbor, to when ocean dumping was banned, and thence to the present when sludge is applied to land as "biosolids." Lessons learned during this long, sometimes contentious history can be applied to present situations—specifically not understanding the long-term consequences of land-based reuse and disposal technologies.

Keywords: Sewage; Land application; Ocean dumping; Biosolids; Sewage sludge

1. Introduction

Human sewage carries pathogenic microbes. When combined with runoff and industrial wastes, as it is in "combined" sewer systems (CSOs), sewage also contains chemical contamination. The management of sewage is basically a matter of prevention of spreading disease and exposing people and wildlife to harmful levels of chemical contamination. Sewage naturally contains nutrients and organic matter that can indirectly (via eutrophication) and directly rob a natural aquatic system of its oxygen content. Therefore, when sewage management includes discharges to marine waters, the characteristics of the sewage and the water body have to be matched to avoid creating noxious conditions and spoiling habitat for marine life. As human population has grown and concerns over the possible detrimental effects of sewage have increased, sewage management options have become fewer and more expensive. This evolution has increased the cost of management but not necessarily its benefits.

2. Background—sludge generated in controversy

Until 1992, New York used its surrounding water, almost exclusively, for sewage management. Prior to the 1880s, sewage was not managed. Sewage washed directly to the Hudson River. Sewage solids were removed from cesspools and privies in populated areas by scavengers (Goldman, 1997) who carried it to land disposal sites,

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used it as fertilizer, or dumped it in the harbor where the solids coated the harbor floor. The introductions of municipally supplied drinking water to private residences and of water closets in the home during the mid-1880s so increased the volume of discharged water in New York City that municipal sewers were needed. Still, the objective was to get sewage to a receiving stream, not necessarily to a treatment plant. Streams were thought to be self-cleansing and disposal of raw sewage into rivers and streams was generally thought by sanitation engineers of the day to be adequate (Tarr et al., 1980). At the turn of the 20th century, public health officials and sanitary engineers disagreed on water quality policy—engineers taking the position that streams could be used for disposal but that water supplies should be purified; public health officials believed that streams and rivers used for water supplies should not be used as receiving waters for raw sewage (Tarr et al., 1980). Since New York is surrounded by saline water, the issue of discharging sewage into water supplies did not arise. It was only in the early 20th century that health effects were recognized from exposure to sewage-borne pathogens via swimming or consumption of raw shellfish. Chlorination of effluents from New York City sewage treatment plants to kill pathogens did not become a regular summertime practice at all treatment plants until 1974 (Brosnan and O'Shea, 1996a).

It was the odor created by too much sewage in too little water that inspired New York's first steps toward sewage treatment. Even before that, Goldman (1997) noted that in the 1880s the New York City Department of Public Works extended new sewage outfalls beyond the bulkhead to the ends of piers so that sewage solids would be flushed by the tidal currents.

Sewage treatment plants (STPs) were introduced to the New York metropolitan region in the late 19th century. The first was constructed in 1884 (Squires, 1981) and six small plants were in operation by 1898 (Loop, 1964). These treated the sewage using chemical precipitation. Much of the treatment, even during the decade of the 1910s was little more than grit removal so that, in effect, sewage flow was briefly retarded and screened prior to entering a waterway (Loop, 1964). The specifications for the removal by grit chambers and screening would not meet modern standards. Grit removal and sedimentation could remove about 60% of the solids and 30% of the organic matter; screens removed 15% of both solids and organic matter (Loop, 1964). Moreover the sludge was dumped in the harbor, somewhat further away from the city than was provided for by discharge pipes. This procedure did not solve the odor problem for very long. Problems with sludge in the estuary became evident in the early 20th century with smells arising from poorly flushed areas where sludge settled and putrefied. By 1913, 4 years after measurements were first made, oxygen concentrations were fairly low in parts of the estuary (Squires, 1981).

Prior to 1920, summertime dissolved oxygen concentrations were at less than 20% saturation (NYCDEP, 1991). The need for sewage collection and treatment became imperative in the New York metropolitan region when the New York Bay Pollution Commission and the Metropolitan Sewerage Commission described the condition of New York Harbor as "grave" (Loop, 1964).

The third report of the Metropolitan Sewerage Commission issued in 1914 identifies "sea dumping" as the method to dispose of sewage solids collected at the sites of screens and settling basins. "Tank vessels" would transport these materials "far to sea" for the purpose of disposal (Loop, 1964). The 12-Mile Sewage Sludge Dump Site was identified in 1924. Its location was selected to avoid interfering with navigation, to avoid visible discoloration of the sea surface, and to prevent floatable material from washing up on ocean beaches (Pararas-Carayannis, 1973). The 12-Mile Site, equidistant from the coasts of New York and New Jersey, had no environmental assessment conducted in preparation for its use. However, waste management officials clearly recognized that ocean dumping was good for the public health (O'Leary, 1959) in that it moved pathogens away from areas of direct human contact.

Prior to 1924, sewage and sewage sludge were both placed in New York Harbor. After the 12-Mile Site was opened in 1924, the effects of sewage management on the waters of New York Harbor became a function of the amount and quality of effluent from sewage treatment plants.

The "sludge problem" had moved offshore, but the amount of sludge increased with population increases and the building and upgrading of sewage treatment plants. Today, the three general categories of wastewater treatment are: primary, secondary and tertiary. Primary treatment consists of physical processes such as screening and settling to remove floatable material, solids and suspended solids. Secondary treatment involves biological or chemical oxidation of organic matter. Tertiary treatment includes the additional removal of solids and organic material and constituents such as nitrogen and phosphorus. Each level of treatment progressively increases the volume of sludge. For each million liters of water treated, primary treatment generates 2500–3000 l of sludge, secondary increases this to 15,000–20,000 l and tertiary treatment generates 25,000–30,000 l (EPA, 1993a,b,c).

By 1927, there were 11 fine screening plants operating in New York City—two in Manhattan, six in Queens, one in Brooklyn, and two on Staten Island. The Jamaica Bay plant, upgraded from its original construction in 1903, was the largest and most modern in the country. Several STPs were designed with the intent that they be upgraded to activated sludge plants (Loop, 1964). The Wards Island STP was the first activated sludge plant approved for the City; it became operational in 1937 with an initial design capacity of 681×10^3 m^3 per day (180 mgd) (Loop, 1964). Even as the City began to move aggressively with sewage treatment, only 1.25×10^6 people, about 17% of the City's population (Koebel and Krueckeberg, 1975) had their sewage treated in 1935. This percentage increased with the operation of the Wards Island plant and its concomitant increase in sludge generation.

The quantity of sewage sludge dumped increased almost monotonically until the mid-1970s when it declined slightly while STPs were being upgraded to secondary treatment required by the Clean Water Act. Upon completion of the upgrades, the quantities of sludge generated and dumped increased once again (Massa et al., 1996).

In the late-1980s, nearly all the City was achieving secondary sewage treatment and New York was annually dumping between 4 and 5×10^6 wet tonnes (Hunt et al., 1996a,b). In 40 years, there had been a 193% increase in the annual volume of sludge generated within the City, or a 214% per capita increase. These changes reflect an increase in the population receiving sewage treatment, and some further upgrading from primary to secondary treatment.

This increased treatment greatly improved water quality in New York Harbor. Brosnan and O'Shea (1996a,b) showed that oxygen concentrations in receiving waters increased since the 1970s and that concentrations of indicator bacteria decreased to the point where, in 1993, almost all the waters around New York City met state standards for swimming. The sewage management problem still faced by New York now centers on (1) nitrogen removal in the effluent and (2) the disposal of sludge generated by the treatment.

3. The sludge problem

3.1. Prior to 1972

Consequences of sludge dumping at the 12-Mile Site remained unexamined from 1924 until the US Army Corps of Engineers initiated comprehensive studies of sewage sludge dumping in the mid-1960s by contracting with the Smithsonian Institute and the Bureau of Commercial Fisheries to investigate the impacts of it on the New York Bight (Squires, 1981). This study brought the issues of ocean dumping to the attention of the scientific and political communities, relevant governmental agencies, and the public. It inspired political opposition to the practice whereby, for example, Congressman Richard L. Ottinger used *The New York Times* (February 8, 1970, p. 1) to indict the 12-Mile Site as the "Dead Sea" and caused the newly formed Council on Environmental Quality (CEQ), a staff organization of the White House, to publish "Ocean Dumping: A National Policy" (Council on Environmental Quality, 1970). That report catalogued the volumes of wastes being dumped off US coasts and included a litany, often incorrect, of negative effects that dumping was having on the ocean, marine organisms, and man. The CEQ called for a permitting system to control ocean dumping and an end to the dumping of materials clearly identified as harmful. With specific reference to sewage sludge, the CEQ called for an immediate ban on dumping undigested sludge, a phasing out of the dumping of digested sludge, and a ban on sludges from any new sources.

3.2. 1972–1981

These recommendations resulted in the 1972 enactment (US Congress, 1972) of Public Law-92-532, the "Marine Protection Research and Sanctuaries Act (MPRSA)." The MPRSA required the US Environmental Protection Agency (EPA) to create a permitting process for ocean dumping, and preliminary regulations of 1973 were followed by Final Regulations in 1977 (EPA, 1977). These involved several scientific considerations of a chemical, biological and physical oceanographic nature. While the Final Regulations were intended to define limits on the characteristics of ocean dumped material and sites for dumping, their effect was to gradually end ocean dumping of all materials except dredged material. No permits for dumping were issued to industries and municipalities that were not already dumping before 1972. Permits that were issued were always "Interim" permits written with the stipulation that the permittee was developing a suitable non-ocean disposal option.

There was no technical reason given to end ocean dumping of sewage sludge or industrial waste. Rather the key idea was the MPRSA wording prohibiting ocean dumping that caused "unreasonable degradation." This concept came into the Final Regulations whereby permit applicants had to demonstrate a "need" to dump waste into the ocean rather than reuse it, recycle it, dispose of it on land, or avoid its production in the first place. In effect, degradation of the ocean was deemed "unreasonable" when the waste might have gone elsewhere. This eventually spawned a series of studies in the category of what can be called multi-media assessments (NACOA, 1981; NRC, 1984; OTA, 1987). Since waste needed to be either used or discarded somewhere, the ocean dumping method had to be weighed against alternatives. None of these assessments, however, affected US policy on ocean dumping.

Policy was affected by untoward events in the New York Bight that were incorrectly attributed to ocean dumping. The 1976 washup of marine debris (grease balls, plastic materials, tampon applicators, burnt wood, etc.) on Long Island's south shore beaches (Swanson et al., 1978) and the 1976 hypoxia event that caused extensive benthic mortalities throughout the Bight (Swanson and Sindermann, 1979), were caused by the intersection of other pollution sources and unusual environmental processes. While the National Oceanographic and Atmospheric Administration (NOAA) established that these occurrences were unrelated to dumping (Swanson et al., 1979), public pressure to end dumping grew.

In 1977, The US Congress (1977), dissatisfied with the EPA's progress toward meeting its own goal to end ocean dumping, codified a 1981 deadline in the 1977 Ocean Dumping Act Amendments (P.L. 95–153). The US General Accounting Office (GAO, 1977) reported to Congress on the status of implementing the Ocean Dumping Act. The report documented the fact that New York and New Jersey sewage sludges were not meeting EPA's disposal criteria. It also noted, despite Congressional intent to end dumping, that alternative methods of sludge management might cause more environmental harm than ocean dumping. The National Advisory Committee on Oceans and Atmospheres (NACOA) reviewed the National policy to end ocean dumping and concluded that the policy was flawed. They determined that scientific evidence did not support the cessation of dumping; the issue was one of protecting one environmental medium (water) at the expense of the others (land and air). NACOA (1981) suggested that, when necessary to use the environment for waste disposal, a "multimedia assessment" be undertaken. That is, environmental effects of the sewage sludge disposal should be considered for air, land and water.

The need for multimedia environmental assessments of sewage sludge disposal, including costs, came to a head when New York City sued the EPA for failing to renew its permit to dump. The basis for the suit was that the EPA had failed to show that dumping of sewage sludge had "unreasonably degraded" the marine environment and in effect New York City "needed" to ocean dump. The US District Court, Southern District of New York ruled in favor of the City (Swanson et al., 1985). The City was thus allowed to continue dumping at the 12-Mile Site, and the date for the cessation of dumping in 1981 was null and void. Two other New York communities and six New Jersey communities/authorities enjoined the suit and were also allowed to continue dumping. The Federal government did not appeal this decision.

3.3. 1981–1987

The courts, and the Reagan era of deregulation (e.g., see Executive Order 12291, signed 17 February 1981), extended the opportunity to ocean dump. For a while it appeared that other cities would attempt to join those communities that were dumping sewage sludge (Swanson and Devine, 1982). Thus, there was a major policy shift by the Federal government in the early 1980s—from that of protecting the ocean from some forms of pollution to one of balancing adverse environmental effects, including costs, of disposal in other media. Cohen (1986) states "waste disposal is today considered an acceptable use of the oceans *under certain conditions*."

Nonetheless, while not actually prohibiting the practice, the EPA, in 1985, began denying and eventually denied petitions by New York and New Jersey municipalities to continue use of the 12-Mile Site. The agency designated an area of the 106-Mile Chemical Waste Dumpsite for sewage sludge (Federal Register, 1984). This site shift, completed in 1987, greatly increased the cost of sludge dumping because of the much longer transit time and because new ocean going vessels were required. At the time of the site relocation, the 12-Mile Site was one of the largest dumping operations in the world in terms of volume dumped (Norton and Champ, 1989).

3.4. 1987 to the end of ocean dumping of sewage sludge

NOAA and the EPA shifted their attention from research on effects at the 12-Mile Site to assessment of future consequences of sludge dumping at the 106-Mile Site. Sludge settling and dispersion calculations (O'Connor et al., 1983) and hazard assessment investigations (Pearce et al., 1983) indicated the potential zone of influence of dumping and the biological resources at risk. Key conclusions of the sewage sludge deep ocean dumping research (Hunt et al., 1996a,b) included: rapid initial dilution, extensive farfield dilution, and no violations of water quality criteria in or downstream of the site. Further, projections indicated little or no transport of sludge onto the continental shelf, only a small flux to the benthic environment, and limited bioaccumulation of sludge related contaminants in organisms (Hunt et al., 1996a,b).

Based on these assessments and regulatory criteria, specifications for the dimensions and use of the site were developed as part of the site designation process. Use of the site commenced in 1986 (Hunt et al., 1996a,b). Some scientists and policy makers believed that an unspoken benefit of moving the sludge dump site 185 km (100 nautical miles) further to sea would be that the increased costs of dumping would encourage municipalities to develop alternative disposal venues. This was not the case however, as the estimated costs of implementing land-based alternatives for New York City sludge was nearly an order of magnitude greater than ocean dumping at the 106-Mile Site. Koch (1988) reported that the capital cost to dump at the 106-Mile Site was $41 million with an annual operating cost of $14 million. The 1992 cost of implementing the City's land-based sludge disposal and reuse program was about $260 million including both capital and operating costs (Swanson, 1993). To verify the government's assertions about the 106-Mile Site, the EPA (1992) implemented a monitoring program.

Nonetheless, despite all the studies, planning exercises, political oversight, interagency negotiation, a new series of marine environmental crises would ultimately end ocean dumping of sewage sludge in the United States (US). In summer 1987, the New Jersey shore experienced a washup of sewage-related marine debris similar to that experienced on Long Island in 1976. Beach related industries suffered a several billion dollar loss of income (Swanson et al., 1991). Almost simultaneously and continuing to March 1988, dead and dying bottlenose dolphin, *Tursiops truncatus*, washed ashore along the east coast from New Jersey to Florida (Geraci, 1989). Another major washup of sewage related material and some medically related debris, including used syringes, occurred on the south shore of Long Island throughout the summer of 1988 as well as further north to Cape Cod. An outbreak of shell disease in deep sea red crabs (*Geryon quinquedens*) inhabiting several of the submarine canyons cutting into the continental shelf of the Mid-Atlantic Bight was reported by commercial fisherman. These events were exhaustively covered by the mass media culminating in cover stories about degradation of coastal waters in the 1 August, 1988 issues of *Time* and *Newsweek*. Sewage sludge dumping at the newly designated deepwater dumpsite was identified as the culprit by some environmental groups, commercial fisherman, and politicians. Once more it was shown that ocean dumping was not the causative factor in any of these instances.

The 1987 and 1988 washups of marine debris were primarily a consequence of debris washed through CSOs by heavy rains and thence transported to the respective shorelines by the prevailing winds (Swanson and Zimmer, 1990). Recent studies concerning the dolphin deaths indicate they were caused by a morbillivirus—a virus suppressing the immune system leaving the animal vulnerable to secondary infections (Lipscomb et al., 1994). Barrett et al. (1993) determined that the strain of morbillivirus that attacked the dolphin was derived from other marine mammal species; it was not related to human or canine sources that might have been in anthropogenic wastes. Young (1989) showed that exoskeleton disease occurred in populations of red crab from the area of concern over the past century—long before any ocean dumping of sewage sludge occurred. Further, he determined that the disease in 1988 was prevalent in organisms caught in canyons well upstream from the 106-Mile Dumpsite raising the question of how the crabs had been exposed to sewage sludge. While he did not rule out that sewage sludge could cause shell disease, he indicated that there were many other variables that might have contributed to this particular outbreak.

Regardless of the results of these investigations, public hysteria and political concern about the condition of coastal waters were sufficiently extensive to preclude rational discussion of the real impacts of sludge dumping. The press was particularly remiss with regard to separating dumping issues and effects from other pollution sources and effects (Quinn, 1997). Beach related industries, restaurants, gift shops, amusements, hot dog vendors, blamed their economic woes on ocean dumping. The US Congress renewed its two decade-long effort to end dumping justified in a manner similar to environmental groups. Consequently, in late 1988, the US Congress passed the Ocean Dumping Ban Act (P.L. 100-688) unanimously in both houses. The Act prohibits ocean dumping or the shipping of sewage sludge to sea for the purpose of disposal after 31 December 1991 (US Congress, 1988).

As ocean dumping of sewage sludge was phased out in the US, NOAA and the EPA monitored the "recovery" of the 12-Mile Site and possible degradation of the 106-Mile Site. These research and monitoring efforts had no impact on policy development at the time. NOAA's Sandy Hook Laboratory found, based on the increased population of invertebrates and the changes in species composition, that the 12-Mile Site was recovering from six decades of ocean dumping after only 2 years (Studholme et al., 1991). Monitoring studies conducted over 6 years at the 106-Mile Site, for the most part, confirmed the earlier assessments (Hunt et al., 1996a).

It should be noted that ocean dumping of sewage sludge is allowed under international treatise, provided that suitable considerations are made of its chemical contamination, of possibilities for reuse, and of alternative methods of disposal (IMO, 1972, 1996).

3.5. Effects of ocean dumping

While the effects of ocean dumping of sewage sludge did not justify the hysteria that led to its prohibition, it was not harmless. Portions of the sludge did not disperse in the water column but, rather, settled to seafloor in the Christiaensen Basin, a depositional area to the northwest in the dumpsite. About 75 km^2 (22 nautical $miles^2$) of seafloor in the Christiaensen Basin were degraded (Gunnerson et al., 1982). The degradation within the substrate, which included organic enrichment, lowered oxygen concentrations and increased contaminant concentrations, caused the benthic community of organisms to become dominated by pollutant tolerant worms to the exclusion of many species that would otherwise characterize the basin. Over a much larger area, 400 km^2 (116 nautical $miles^2$), it became illegal to harvest clams or any other shellfish that would be eaten raw. In May of 1970 (Verber, 1976), the Federal Food and Drug Administration (FDA) prohibited shellfish harvesting (oyster, clam, and mussels; not crustacean shellfish or scallops that are usually cooked and usually not eaten whole) over a 22.2 km (12 nautical mile) diameter circle centered on the sludge dump site. This closure was done because concentrations of coliform bacteria (indicators of human waste and possible pathogens) in overlying waters exceeded FDA standards. That area was extended to the shorelines of New York and New Jersey in 1974 (Verber, 1976). In 1989, after the 12-Mile Site was closed, coliform concentrations in surface waters near the site were well within acceptable limits for shellfishing and the area could have been reopened (Gaines and Reid, 1995). Gaines and Reid point out that more than 99% of the coliform bacteria within the closure zone were probably delivered not by ocean dumping but by the Hudson River which in the 1970s was receiving unchlorinated sewage. Nonetheless, the shellfishing closure was the first negative effect on marine resources officially, attributed to ocean dumping of sludge.

Sewage sludge by its very nature contains highly organic particles and human pathogens. So, depending on the amounts and where it is dumped at sea, it can change the seafloor and present a public health hazard. New York City sludge, like that from all urban areas especially those with CSOs, also contains inorganic and organic chemicals that could be toxic and which could be accumulated by fishes and shellfishes destined for human consumption. Concerns over this chemical contamination had always been part of the objection to sludge.

Because of the 106-Mite Site's distance from land and the prevailing currents, dumping at the site eliminated any exposure of humans to sludge-derived pathogens. Because the water is deep (2500 m), particles remain waterborne and subject to dispersion for much longer times than when dumped at the (10 m deep) 12-Mile Site. O'Connor et al. (1983) suggested that the flux of sludge onto the seafloor would be too low to be detected in sediment samples and that measuring the flux would require intercepting sludge in sediment traps. After sludge dumping began, traps were deployed and evidence of sludge was found downstream some 100 km (Hunt et al., 1996b). However, Bothner et al. (1994), carefully sampling sediment from the deep submersible Alvin, found sludge directly on the sea floor as evidenced by concentrations of chemicals that are uniquely elevated in sludge relative to natural sediment. Van Dover et al. (1992) had previously reported that sulfur and nitrogen isotope ratios in deposit feeding benthic organisms collected at the 106-Site showed evidence of the organisms having ingested sludge.

4. Sludge goes to land

With the ocean option closed, New York City sludge has gone to land. Sludge is considered a pollutant on the seafloor. On land, however, its organic content and to a lesser extent the nutrient content make it potentially useful as a soil conditioner on agricultural and forest lands, and also on highway median strips and interchanges (EPA, 1993a). It can be used for land reclamation, e.g., the stabilization of strip mines, landslides, forest fires, and dredge material fills (Cheremisinoff, 1994). Sludge can also be used as cover for landfills (though the Ocean Dumping Ban Act prohibits this use at the world's largest landfill, the Fresh Kills Landfill on Staten Island, NY). However, constituents of concern—pathogens, toxic metals, synthetic organic hydrocarbons—identified as problems for ocean dumping are also in sewage sludge used in these land application strategies.

As pressure built to end ocean dumping, and the nation was raising its consciousness concerning recycling, a number of sewage authorities challenged the EPA to assess accurately the risks of land application. They lobbied that the regulations for land application of sewage sludge were too restrictive, limiting the opportunities for beneficial reuse of sludge (EPA, 1990). As an aid to gaining acceptance of sludge for that use, sanitation officials introduced new terminology so that henceforth, processed sewage sludge has been known as "biosolids."

In 1988, the EPA did undertake a more comprehensive National Sewage Sludge Survey which involved sampling from 180 STPs for some 400 toxic/potentially carcinogenic contaminants. In addition, the agency surveyed more than 450 STPs concerning sludge use and disposal practices. Some of the contaminants measured included chlorinated organic compounds, pesticides, dibenzofurans, dioxins, polyaromatic hydrocarbons (PAHs), PCBs, a number of metals, and inorganic constituents (EPA, 1990). The EPA then developed limiting concentrations on the basis of a lengthy risk assessment (EPA, 1993b,c) that considered 14 pathways for chemicals to migrate from sludge-amended soil to plants, animals, and humans. The limiting concentrations for As, Cd, Pb, Hg, and Se are based on preventing sickness among children directly ingesting sludge. For those elements, all other pathways to humans and all effects on plants or animals were calculated to result in higher limiting concentrations. The limiting concentrations for Cr, Cu, Ni, and Zn are based on preventing toxicity to crops. Limits for some organic chemicals were derived, but were not made part of criteria for land application for one or more reasons: the chemical has been banned for use in the US; the chemical was detected in less than 5% of the sludges tested in the National Sewage Sludge Survey; or, based on the Survey results and assessments of exposure, concentrations would rarely exceed limits calculated to pose unacceptable risks. For some organic compounds, limiting concentrations were based on direct ingestion by humans. For other organic compounds, the limit was based on human consumption of livestock grazing on sludge-amended land. For DDT, the limit was based on a runoff model and pre-existing water quality criteria. The chemical concentrations in New York City sludge fall well within the limits for land application.

The National Research Council reviewed the EPA criteria for sludge applied to land in 1996 (NRC, 1996) and again in 2002 (NRC, 2002). Questions on the limiting concentrations of chemicals have centered on the risk assessment procedures and, especially, on the exclusion of limits on organic contaminants. The practical consideration on organic limits is that, if they were imposed, biosolid generators would be required to periodically measure the organic chemical concentrations in their product. Since EPA (1993a) recognized that the limits derived from the risk assessment would almost never be exceeded, the cost of measuring the chemicals in sludge was not justified. Land application is now used by two/thirds of the STPs in the US, so questions of limits and standards have implications well beyond New York City sludge management. The NRC reviews stem from a continuing public concern about the practice. The NRC (2002) wrote

"There is no documented scientific evidence that the Part 503 rule [EPA sludge criteria] has failed to protect public health. However, additional scientific work is needed to reduce persistent uncertainty about the potential for adverse human health effects from exposure to biosolids. There have been anecdotal allegations of disease, and many scientific advances have occurred since the Part 503 rule was promulgated. To assure the public and to protect public health, there is a critical need to update the scientific basis of the rule to (1) ensure that the chemical and pathogenic standards are supported by current scientific data and risk-assessment methods, (2) demonstrate effective enforcement of the Part 503 rule, and (3) validate the effectiveness of biosolids-management practices."

Most concerns seem to be in regard to the pathogens rather than the chemicals in sludge. Land applied sludge is in two categories A and B. Category A sludge must be treated in one of six prescribed ways to reduce specified pathogens to below specified detection limits. Category B sludge can have detectable pathogens. The practical difference between category A and B sludges is that the former can be used without concern for immediate human contact while use of the latter involves site restrictions limiting human contact until natural process have reduced pathogens to below detection. NRC (2002) found that "the reliability of EPAs prescribed treatment techniques should be better documented using current pathogen detection technology, and more research on environmental persistence and dose response relationships is needed to verify that current management controls for pathogens are adequate to maintain minimal exposure concentrations over an extended period of time."

The NRC seems to believe that land application of sludge is a safe practice and that more technical studies will eventually allay public concerns. Many scientists held the same opinion about ocean dumping, but the political pressure eventually banned it in the US. The New York City situation typifies that of most coastal cities. Sludge can be dumped at sea with some environmental change and no threat to public health, but public pressures, nonetheless, forced an option of land application. Now questions linger as to land application's threat to human health. Liability associated with use and transfer of property that has been used for biosolids application is also likely to become an issue.

Meanwhile the monetary costs of moving from the sea to the land option are high. The costs for managing New York City's sewage sludge in 2002 (about 10 million wet tons) would have been \$5.3 million if it had been dumped at the 12-Mile Site and \$23.4 million if it had been dumped at the 106-Mile Site. The land application cost was \$54.4 million (Theresa Norris, NYC Department of Environmental Protection, personal communication). The latter cost is actually higher because it does not include the \$600 million (NYCDEP, 1990) capital cost of centrifugation used to dewater sludge or the approximately \$12 million annual cost to operate them. Increased costs of moving to the 106-Mile Site are due essentially to additional transportation costs. The increase for land application includes the cost of reducing wet sludge to dry biosolids and the cost of transporting the biosolids to several states throughout the US (not including New York) where the material is used.

5. Conclusion

New York City began ocean dumping of sewage at the 12-Mile Site in 1924 to relieve a dismal condition in New York Harbor which actually putrefied in places as a result of decay of sewage. While in 1970 a 400 km^2 (116 nautical $miles^2$) area around the site was closed to shellfishing as a public health measure, it was later observed that indicator bacteria were coming from STP discharges, *as well as from* sludge. There was accumulation of sludge particles in the Christiaensen Basin and consequent changes in the numbers and types of benthic organisms. From 1970 to 1986, the practice of dumping at the 12-Mile Site came under increasing pressure stemming from a series of untoward environmental crises in the New York Bight that were attributed partly to sludge dumping. In 1986, sludge dumping was moved to the 106-Mile Site. Then, again in response to political pressure arising from events unrelated to ocean dumping, the practice ended entirely in 1992. Since 1992, New York City sludge has been applied to land or land filled. That practice, now employed by two/thirds of the STPs in the US, has been under continued scrutiny.

The wider question is whether or not changes on the sea floor caused by the settling of sewage sludge are severe enough to justify the three-fold added operational cost and human health concerns of applying sludge to land. Within the US, where ocean dumping of sludge is banned, the cost versus benefit question is academic, but on a global basis, as more and more sewage is treated, every sludge management option deserves practical consideration.

5.1. Disclaimer

The views in this article are those of the authors and do not necessarily reflect the official policy or position of NOAA, the Department of Commerce, or the US Government.

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